Chapter 12. Petrified Forest National Park

Introduction

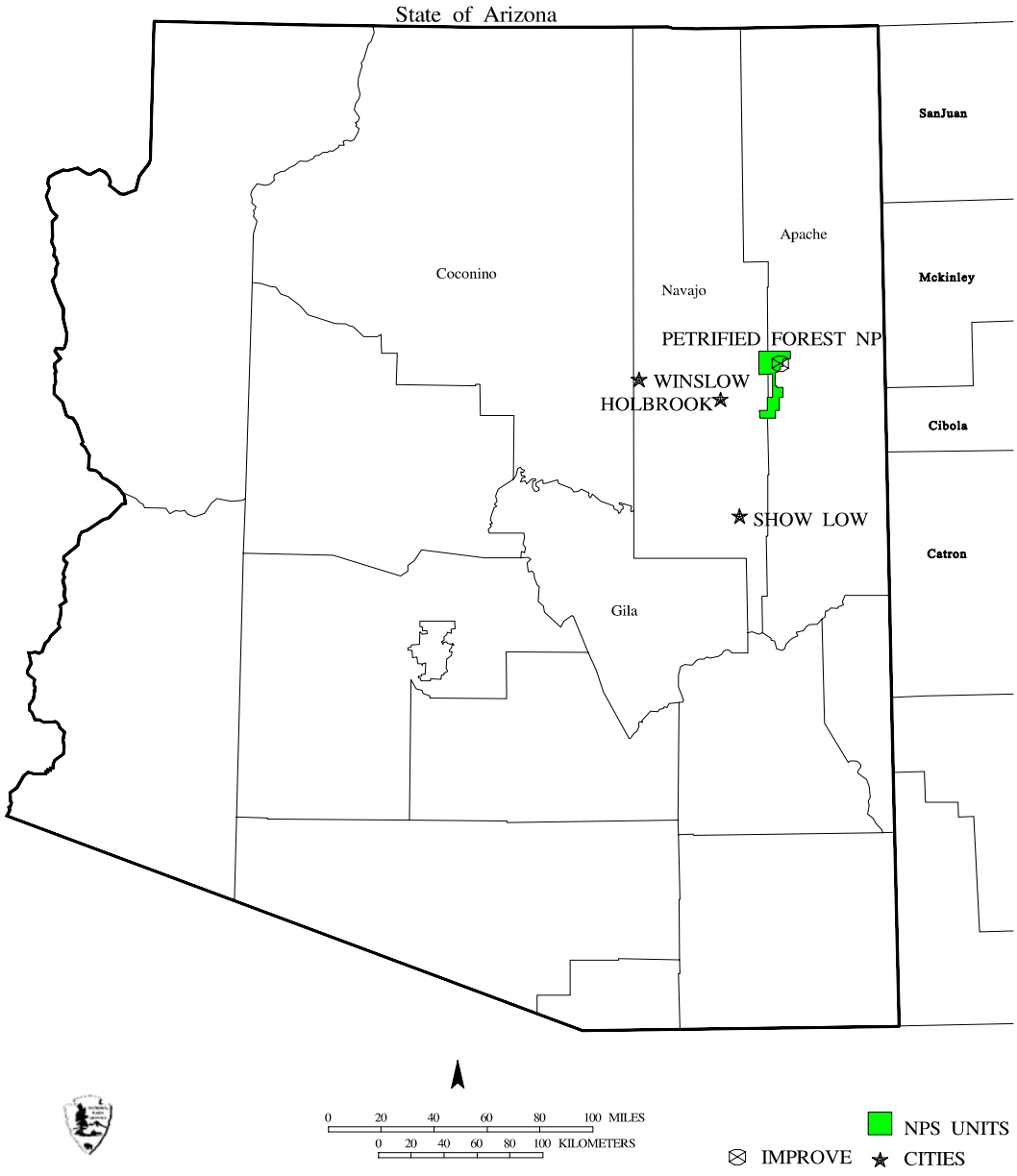
Petrified Forest National Park was established as a national monument in 1906 under the American Antiquities Act of 1906; the monument was converted to a national park in 1962. The Park is comprised of 37,900 ha (all federally owned), including about 20,000 ha of designated wilderness. The park was established to protect and preserve three primary features: petrified trees from the Triassic Period; various archeological ruins and petroglyphs; and portions of the colorful Painted Desert and associated badlands erosional formations. Petrified Forest National Park is located between 1600 and 1900 m in Apache County in northeastern Arizona on the southern end of the Colorado Plateau (Figure 12-1).

Geology and Soils

The geology of Petrified Forest National Park began in the Triassic Period about 225 million years ago, when the region was an expansive floodplain that stretched from volcanic mountain ranges in south-central Arizona to low country in northern Arizona. Surrounding higher elevation areas were forested with primitive conifers. Over a period of millions of years, shorter periods of active volcanism killed these trees and they were toppled and sometimes transported downslope into the marshy floodplain. Once in the floodplain, they were quickly buried by layers of volcanic ash, sand, silt and clay. Conditions were favorable for silica from the water to slowly infiltrate plant cells, imbedding the organic material in silica crystals of beautiful colors that characterize the petrified wood of the Park and the region. The same processes that resulted in the burial of trees also resulted in the Chinle Formation, which is exposed today as the shales of the Painted Desert.

During the Cretaceous Period, seas advanced once again and thick shales and sandstone layers were laid down. About 70 million years ago the region began to uplift, the seas withdrew and erosional processes dominated the geologic development of the landscape. The Chinle Formation

Figure 12-1. Location of Petrified Forest National Park.



is comprised of mudstone and shale material that largely weathers into smectite clays with shrink swell properties (often called bentonite). These “badland” desert systems are sparsely vegetated because plants have great difficulty in establishing in the easily eroded, shrinking and swelling soils (Chronic 1988). A soil survey was conducted for Apache County that details the soils of the Park. There are roughly five main soil types broken down into various series, most of which have their origin in the Chinle Formation or younger sandstones of the later Mesozoic. Most soils are characterized by shallow development, high erosion, and low water permeability.

Climate

The climate of Petrified Forest is semi-arid, receiving about 270 mm/yr of precipitation (Figure 12-2). Most of the rain falls during the winter and spring months, with a second peak during the mid-summer monsoons. Temperature are moderately high in the summer (averaging 24 ^{o}C), and moderately cold in the winter (averaging -2 ^{o}C). The winds in winter come from the west, southwest, and south, shifting to southeast and east in the summer and autumn (Figure 12-3).

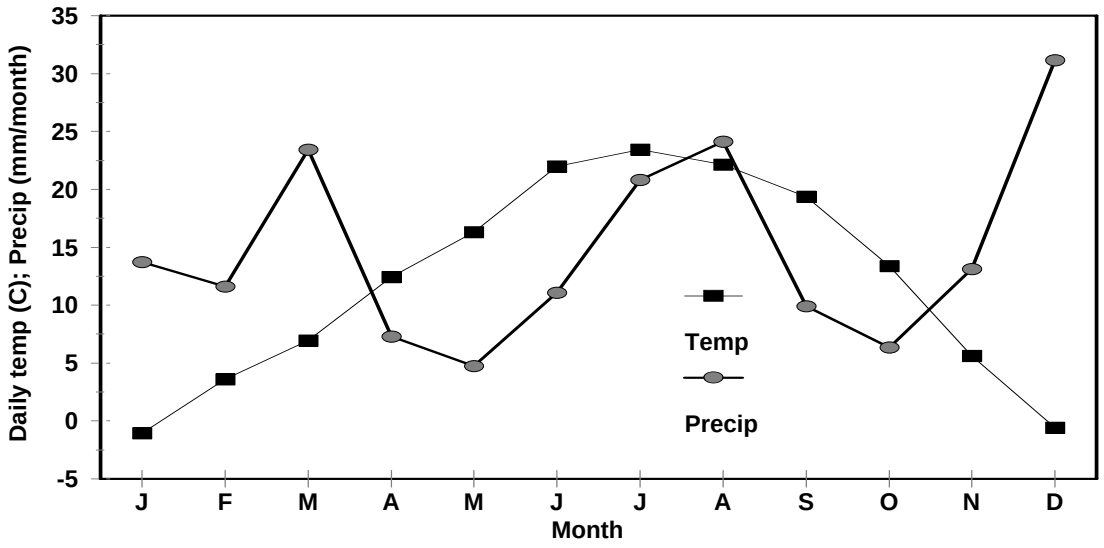
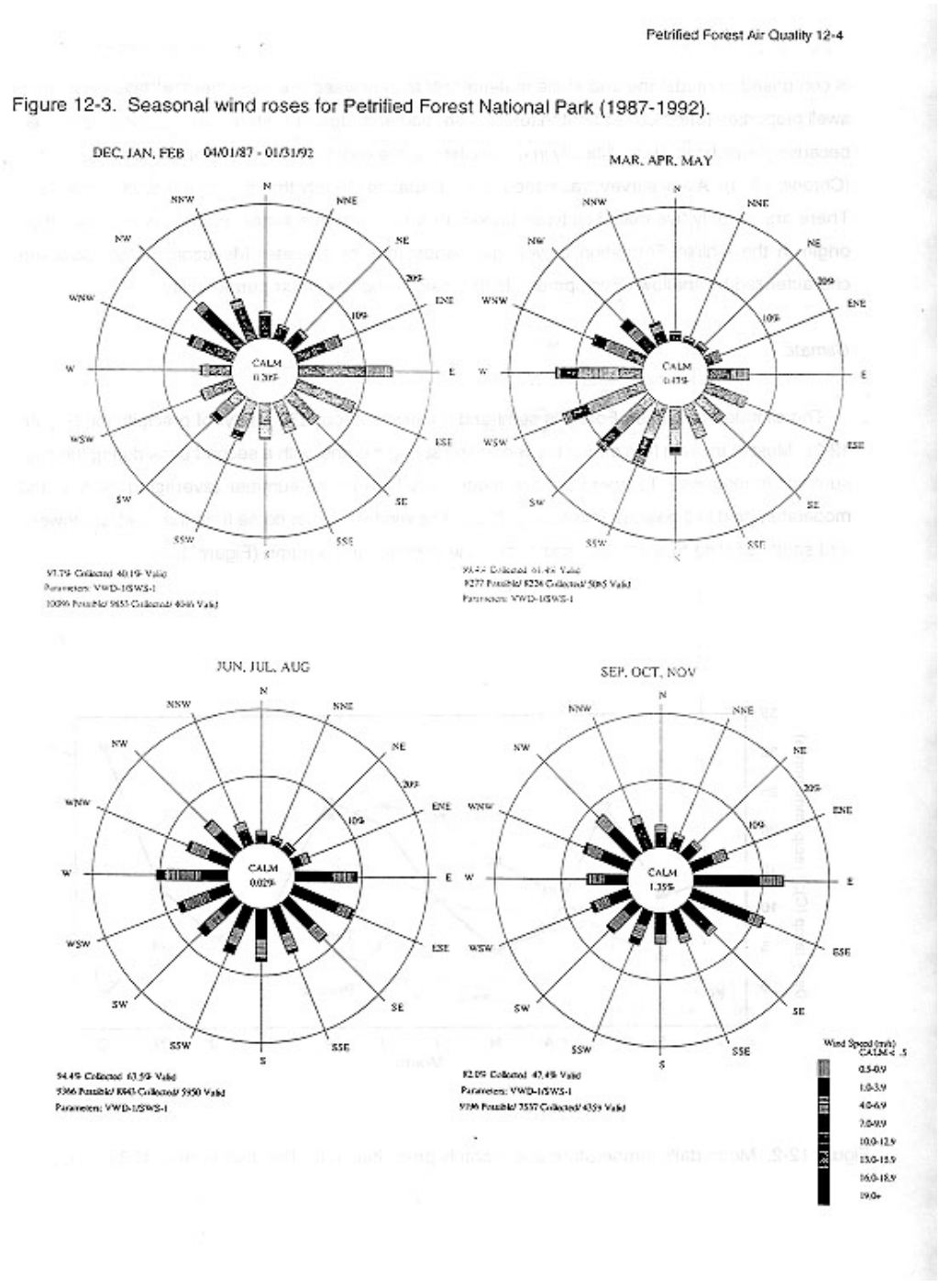


Figure 12-3. Seasonal wind roses for Petrified Forest National Park (1987-1992).



Vegetation

The vegetation of Petrified Forest National Park is dominated by semi-desert grasslands, with some conifer woodland communities at the northern end of the park. The dominant grass species in the grasslands are *Bouteloua eriopoda*, *Pleuraphis jamesii*, and *Sporobolus* spp., with scattered rabbitbrush (*Chrysothamnus* spp.), saltbush (*Atriplex* spp.), sagebrush (*Artemisia* spp.), Mormon tea (*Ephedra* spp.) and juniper (*Juniperus monosperma*). In the woodland communities, juniper dominates with some pinyon pine (*Pinus edulis*) and other shrubs. There is currently little information about the distribution and abundance of plant species across the Park and no vegetation monitoring program is in place to document the current distribution and abundance and potential future changes. No information is available on the distribution or abundance of exotic species. A listing of plant species is provided by NPFlora. The Park has one known endangered plant species: the cactus *Pediocactus peeblesianus* (Threatened and Endangered Species Information Institute 1993). Species of special concern to the NPS are *Astragalus xiphoides* and *Pediocactus papyracanthus*. No listing is available in NPLichen for the Park, but a survey was done by a graduate student (Davis 1992).

Air Quality

Air quality monitoring for Petrified Forest National Park consists of ozone data from 1987-1991, sulfur dioxide measurements for 1988, and IMPROVE monitoring for visibility from 1988 to the present (from Jasper Forest to Blue Mesa for transmissometer; from 1 km northeast of park headquarters for the camera; at park headquarters for the particulate sampler). No NADP site is close enough for direct use in estimating deposition for Petrified Forest.

Emissions

Table 12-1 provides summaries for emissions of carbon monoxide (CO), ammonia (NH_3), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM), and sulfur oxides (SO_x) for 8 counties surrounding Petrified Forest. Many large point-sources of SO_x occur in these counties, including: two Salt River Project stations (in Coconino and Apache Counties) , and two Arizona Public Service power stations (in Navajo County, Arizona, and San Juan County, New Mexico). No information is available to relate these emissions to air quality at Petrified Forest, or to apportion Petrified Forest's air quality impairment to local and regional sources.

Table 12-1. Emissions (tons/day) for counties surrounding Petrified Forest National Park (Radian 1994).

County	CO	NH_3	NO_x	VOC	PM	SO_x
Apache, AZ	139	3.2	83	118	554	64
Coconino, AZ	146	3.2	133	209	659	213
Gila, AZ	71	1.2	13	79	246	93
Navajo, AZ	167	2.7	79	83	559	68
Catron, NM	12	1.6	1	83	170	0
Cibola, NM	6	0.1	4	--	199	2
McKinley, NM	151	2.2	41	47	320	8
San Juan, NM	167	1.2	197	50	372	176

Air Pollutant Concentrations

The average concentrations of ozone in 1987-1991 were low, about 40 ppb (Table 12-2). However, Petrified Forest consistently had higher peak concentrations (from 97 to 134 ppb for 1-hr maximum) than any of the Parks or Monuments on the Colorado Plateau. The average concentrations are too low to cause any impact on sensitive species, but the peak concentrations are into the middle range of concentrations that affect sensitive species, and cumulative exposures may be near the lower threshold for effects on sensitive species (see Chapter 2). No reports of injury or growth effects have been noted. The concentrations of SO_2 were far below any threshold of suggested sensitivity for any plants.

Table 12-2. Concentrations of ozone and SO_2 for Petrified Forest National Park between May and September. For ozone, upper value is mean daily concentration (ppb); middle number is the maximum 3-month Sum60 exposure (ppb-hr in excess of 60 ppb for 12 hr/day); and bottom number is the maximum 1-hr concentration observed each year. SO_2 24-hr averages by IMPROVE filter samplers (ppb) (1 $\mu g/m^3$ approximately equals 0.38 ppb). Ozone data from the NPS Air Resources Division's Quick Look Annual Summary Statistics Reports (provided by D. Joseph, NPS-ARD).

Year	Ozone	SO_2
1987		
Mean	42	
Sum60	19056	
Max	116	
1988		
Mean	39	0.2
Sum60	6933	
Max	101	0.8
1989		
Mean	43	
Sum60	13496	
Max	104	
1990		
Mean	40	
Sum60	10362	
Max	97	
1991		
Mean	41	
Sum60	10776	
Max	134	

Visibility

Visual air quality was monitored using a transmissometer, aerosol sampler and a camera. Petrified Forest National Park is part of the IMPROVE Monitoring Network. The transmissometer began operation in April 1987, the aerosol sampler began operation in March 1988, and the camera operated from July 1986 through April 1995. The data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for April 1987 through February 1994, based on seasons of spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February).

Optical Data - Transmissometer

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The atmospheric extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and that measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Weather factors such as clouds and rain can affect transmissometer measurements, but these can be "filtered out" by removing data points with high relative humidities (RH>90%).

The data are presented by season and annual median values, with and without meteorological factors in Table 12-3. The data are presented in units of extinction coefficient in Mm^{-1} and standard visual range in km. Extinction coefficients represent the ability of the atmosphere to scatter and absorb light. Median values with large differences between the extinction values "including weather" and "excluding weather" indicate periods dominated by precipitation. Higher extinction coefficients signify lower visibility. Similarly, season and annual medians with nearly equal "including weather" and "excluding weather" extinctions indicate visibility reduction caused principally by particles. Visibility tends to be worst in the summer (Table 12-4).

Table 12-3. Transmissometer data summary for Petrified Forest National Park for 1987-1994. (SVR = standard visual range; b_{ext} = light extinction coefficient.)

Season Year	Excluding Weather		Including Weather	
	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})
Spring 1987	139	28	134	29
Summer	125	31	121	32
Autumn 1987	162	24	144	27
Annual 1987	140	28	135	29
Winter 1988	227	17	194	20
Spring 1988	169	23	162	24
Summer	134	29	130	30
Autumn 1988	139	28	130	30
Annual 1988	149	26	139	28
Winter 1989	194	20	176	22
Spring 1989	121	32	121	32
Summer	102	38	97	40
Autumn 1989	139	28	134	29
Annual 1989	130	30	125	31
Winter 1990	149	26	144	27
Spring 1990	149	26	149	26
Summer	134	29	130	30
Autumn 1990	130	30	121	32
Annual 1990	139	28	134	29
Winter 1991	121	32	114	34
Spring 1991	111	35	111	35
Summer	114	34	111	35
Autumn 1991	130	30	125	31
Annual 1991	118	33	114	34
Winter 1992	134	29	71	55
Spring 1992	114	34	111	35
Summer	114	34	111	35
Autumn 1992	125	31	121	32
Annual 1992	118	33	111	35
Winter 1993	134	29	114	34
Spring 1993	121	32	118	33
Summer	125	31	121	32
Autumn 1993	144	27	134	29
Annual 1993	134	29	125	31
Winter 1994	144	27	144	27
Spring 1994	121	32	118	33
Summer	118	33	118	33
Autumn 1994	155	25	149	26
Annual 1994	134	29	130	30

Table 12-4. Standard visual range for Petrified Forest National Park. Seasonal averages for median standard visual range in km from April 1987 - November 1994.

Season	Excluding Weather	Including Weather
Winter	158	137
Spring	131	128
Summer	121	117
Autumn	140	132

Aerosol Data

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient from experimentally determined extinction efficiencies of certain species (Table 12-5). To compare this table with the data from Table 12-3 and 12-4, the "excluding weather" values should be used. In Table 12-5 the data are presented as seasonal and annual 50th and 90th percentile standard visual range for Petrified Forest. The 50th percentile means that visual range is this high or lower 50% of the time. This is an average 50th percentile for each season. The 90th percentile means that the visual range is this high or lower 90% of the time. This is an average 90th percentile for each season. The estimated visual ranges and light extinction coefficients are similar for both the transmissometer measurements and the reconstructed values based on aerosol concentrations.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions. The measured extinction data are used to verify the calculated reconstructed extinction and can also be used to run plume and regional haze models and to analyze visibility trends and conditions. Because of the larger spatial and temporal range of the aerosol data, the use of the reconstructed extinction data are preferred.

Table 12-5. Reconstructed visual range and light extinction coefficients for Petrified Forest National Park, based on IMPROVE aerosol sampler, seasonal and annual average 50th and 90th percentile by season, March 1988 - February 1994.

Season/Annual	50th Percentile Visual Range (km)	50th Percentile b_{ext} (Mm^{-1})	90th Percentile Visual Range (km)	90th Percentile b_{ext} (Mm^{-1})
Winter	105	37.1	161	24.3
Spring	120	32.6	157	24.9
Summer	102	38.2	131	29.9
Autumn	109	36.0	147	26.7
Annual	107	36.5	154	25.3

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at Petrified Forest National Park to specific aerosol species (Figure 12-4). Visibility impairment is attributed to atmospheric gases (Rayleigh scattering), sulfate, nitrate, organics, soot, and coarse particles. The extinction budgets are listed by season and by mean of cleanest 20% of days, mean of median 20% of days, and mean of dirtiest 20% of days. The "dirtiest" and "cleanest" signify the days with the highest fine mass concentrations and lowest fine mass concentrations respectively, with "median" representing the 20% of days with fine mass concentrations in the middle of the distribution. Each budget includes the corresponding extinction coefficient, SVR, and haziness in dv. The sky blue segment at the bottom of each stacked bar represents Rayleigh scattering which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gases. Higher fractions of extinction due to Rayleigh scattering indicate cleaner conditions.

Figure 12-4. Reconstructed extinction budgets for Petrified Forest National Park, March 1993 through February 1994.

Atmospheric light extinction at Petrified Forest National Park, like many rural western areas, is largely due to sulfate, organic, and soot aerosols. Sulfates, organics, and soot contribute roughly equally to extinction on dirty, median, and clean days. In pre-industrial times, visibility would vary with patterns in weather, winds (and the effects of winds on coarse particles), and smoke from fires. We have no information on how the distribution of visibility conditions at present differs from the profile under "natural" conditions.

Photographs

Three photos are provided to represent the range of visibility conditions for the Petrified Forest National Park transmissometer cumulative frequency data (Figure 12-5). The photos were chosen to provide a feel for the range of visibility conditions possible and to help relate the SVR/extinction/haziness numbers to what the observer sees.

Figure 12-5. Photographs representing visibility conditions at Petrified Forest National Park.

Petrified Forest Air Quality 12-14

Figure 12-5. Photographs representing visibility conditions at Petrified Forest National Park.

Petrified Forest National Park
on a "clear" day.

Petrified Forest National Park
on a "average" day.

Petrified Forest National Park
on a "dirty" day.

Atmospheric Deposition and Water Quality

No NADP site is close enough to Petrified Forest to provide good estimates for deposition; rates are probably similar to those across the region (which are low). No surface water bodies exist in the Park.

Sensitivity of Plants

No signs of injury from air pollution damage have been reported for vegetation in or near Petrified Forest National Park. None of the Park's species have been tested under controlled conditions for sensitivity to pollutants. Based on the ozone concentrations required to affect very sensitive plants, we expect that current ozone exposures (both peak concentrations and cumulative exposure) could be high enough to affect some species. Given the arid climate at Petrified Forest, it is possible that actual doses of ozone received by plants are lower than atmospheric concentrations would suggest; closed stomates during dry periods may substantially reduce ozone effects on plants. Current levels of ozone are the highest for NPS Class I areas of the Colorado Plateau, so some type of screening of major species for sensitivity (using controlled fumigation experiments) may be warranted. Levels of SO_2 are far below any demonstrated threshold of sensitivity for any plants. In the absence of empirical evidence of any effects, no substantial problem is likely.

Recommendations for Future Monitoring and Research

General recommendations for NPS Class I areas of the Colorado Plateau are presented in Chapter 14, and many of these apply to Petrified Forest National Park. Specific recommendations for this Park are:

- An NADP site should be established for monitoring atmospheric deposition. This region has the highest SO_x emissions in the area, and very high ozone concentrations. No NADP sites are close enough to provide representative data for this Class I area. We do not expect deposition rates to pose any imminent risk for AQRVs, but this gap in monitoring is one of the most notable on the Colorado Plateau.
- Some form of ozone monitoring be reinstituted at Petrified Forest, as previous data show very high levels, and no other Colorado Plateau site is close enough to represent conditions at Petrified Forest.
- A variety of plant species from this Park should be included in the controlled ozone fumigation experiments (described in Chapter 14), as many species from this Park do not occur in other NPS

areas of the Colorado Plateau.

Park Summary

Visibility is currently the only AQRV known to be impacted by pollution at Petrified Forest, as with the other National Park Service Class I areas of the Colorado Plateau. Current levels of pollution in northeastern Arizona are high enough to produce haze and obscure the important vistas of the Park and surrounding areas. The ability of visitors to see the subtle pastel colors of the Painted Desert may be particularly sensitive to changes in haziness. Any increase in aerosols will undoubtedly impair visibility further; substantial reductions in aerosols would be needed to restore pristine conditions at Petrified Forest.

Little information has been collected on air pollution effects on the Park's biota. No sign of air pollution impacts on plant or animal species has been reported; ozone concentrations are high enough that some impact is possible for sensitive plants, but SO_2 concentrations are too low to affect plants.

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